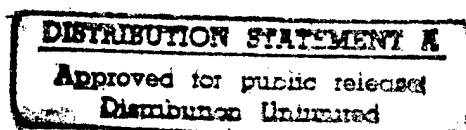# Quarterly Report
Passive Ranging with Incoherent Systems

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1. This confirms our conversations of 27 Feb 97 and 11 Jul 97. Enclosed are a number of technical reports which were returned to our agency for lack of clear distribution availability statement. This confirms that all reports are unclassified and are "APPROVED FOR PUBLIC RELEASE" with no restrictions.

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ROBERT J. SILVERMAN

Passive Ranging with Incoherent Systems

Recent research has concentrated on two main issues. The first concerns high-accuracy passive ranging with a moving unaltered single-aperture system. Such passive ranging systems could be used as passive low-level altimeters. The second point concerns use combined optical and digital systems for aberration control. We have earlier demonstrated use of optical/digital systems for insensitivity to misfocus, or second-order aberrations. We show that this same technique can also be used to compensate for chromatic aberration, astigmatism, thermal effects, and spherical aberration. An important reason for controlling aberrations through combination of optics and digital processing is the possibility of making low precision (i.e. low cost) optical systems that perform as high-precision (i.e. high cost) systems.

Passive Ranging with a Multi-Aperture System

Our research on passive ranging has considered the general ranging system as being a single-aperture, single-image system that has been modified by a special purpose optical mask, with digital processing capability. The requirement of a special purpose mask limits the use of these passive ranging systems with unmodified optical systems. But, by considering a passive array-based ranging system, or equivalently a standard moving single-aperture system, powerful passive ranging concepts that we have developed still apply. Theoretical and experimental work on multi-aperture systems has recently been completed.

When considering the optimum passive ranging system through information theory an important result is that the system transfer function must contain range-dependent spatial frequency nulls [1]. These nulls can be periodic range-dependent nulls as in the passive range detection scheme we have described [1, 2], or these nulls can be uniform with the exception of a range-dependent spectrum peak as in orthogonal passive range estimation systems [1]. Both schemes lead to effective passive ranging systems.

By considering the availability of multiple displaced images of an unknown object, from say a multi-aperture or moving aperture system, an effective passive ranging system can be formed through a linear combination of the displaced images. By correct choice of displaced image weights, an effective image spectrum can be produced that has range-dependent nulls. These nulls are identical in nature to those produced by optimized single-aperture, single-lens passive ranging systems. The extra degrees of freedom allowed by multiple displaced images can thus be exploited to produce an optimum passive ranging system. Recent theoretical and experimental results on multi-aperture passive ranging system has been presented at the last OSA conference in Portland. A copy of this conference paper has been included.

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Wavefront Coding for Aberration Invariance

We have shown that by modifying an incoherent optical system with a cubic phase optical mask the resulting optical system is insensitive to misfocus [3, 4]. Digital filtering of the resulting intermediate image results is imagery with near diffraction-limited spatial resolution and a very large depth of field.

Optical systems that are insensitive to misfocus are, by definition, insensitive to second-order aberrations. Such systems are also insensitive to other aberrations. Consider chromatic aberration. Chromatic aberration results from a system with a wavelength dependent focal length. If the overall optical/digital system is insensitive to misfocus, then it is also insensitive to changes in focal length. Therefore, chromatic aberration can be compensated through wavefront coding.

In general, all aberrations that vary the system focal length can be compensated through wavefront coding optics and digital processing. Astigmatism, where the focal length is different for the vertical and horizontal aspects of the lens system, and thermal effects, where the focal length is a function of temperature, can both be controlled through our extended depth of field method.

Effects of more complicated aberrations, such as spherical aberration, can best be analyzed through the ambiguity function. Through ambiguity function analysis we can show that aberrations similar to spherical aberration also have little effect on the performance of extended depth of field systems. See included paper. This paper was originally prepared for a SPIE conference in Guanajuato, Mexico. The text is currently being prepared for submission as a journal article.

Lens aberrations can be caused by poor optical alignment or equivalently by a low-precision (low-cost) fabrication process. An important aspect of aberration invariant systems is that they lead to low-precision (low cost) systems that perform similar to high-precision (high cost) systems. Therefore, extended depth of field wavefront coded systems can be used not to increase depth of field, but rather for aberration control leading to an overall decrease in system cost.

A journal article describing aberration invariance is currently being written.

References

[1] E. R. Dowski, Jr., "An information theory approach to three incoherent information processing systems," in *Signal Recovery and Synthesis V*, OSA Technical Digest Series, March 1995, pp. 106–108.

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[3] E. R. Dowski, Jr. and W. T. Cathey, "Extended Depth of Field Through Wavefront Coding," *Applied Optics*, vol. 34, pp. 1859–1866, April 1995.

[4] J. van der Gracht, E. Dowski, W. T. Cathey, and J. P. Bowen, "Aspheric Optical Elements for Extended Depth of Field Imaging," in *SPIE Proceedings on Novel*